

# ***Hybrid MBE-CBE Growth and Characterization of $Al_{0.48}In_{0.52}As$ on $InP(100)$ for avalanche photodiode applications***

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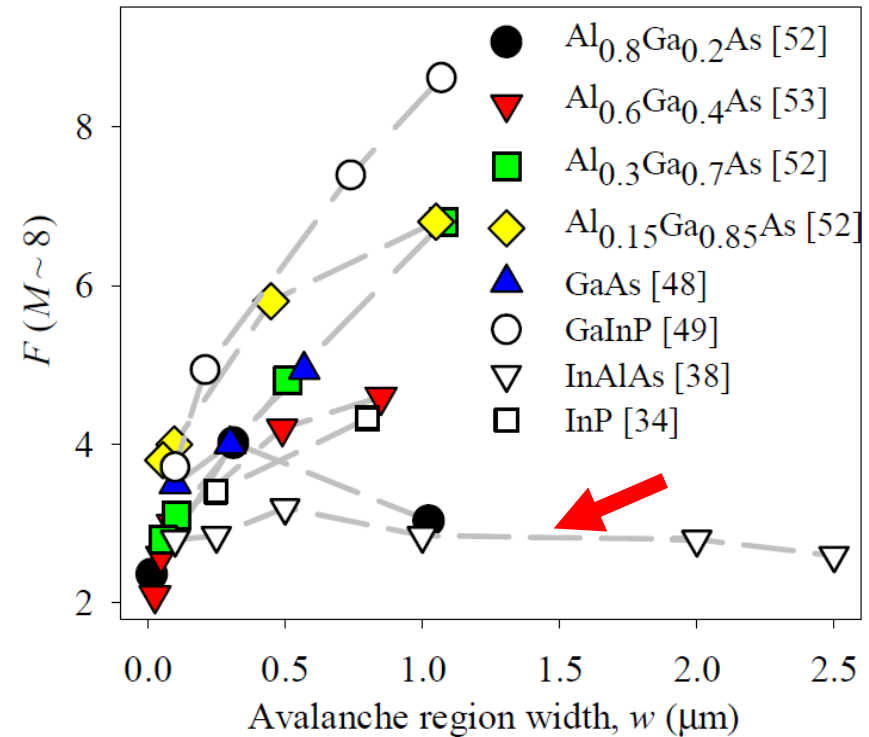
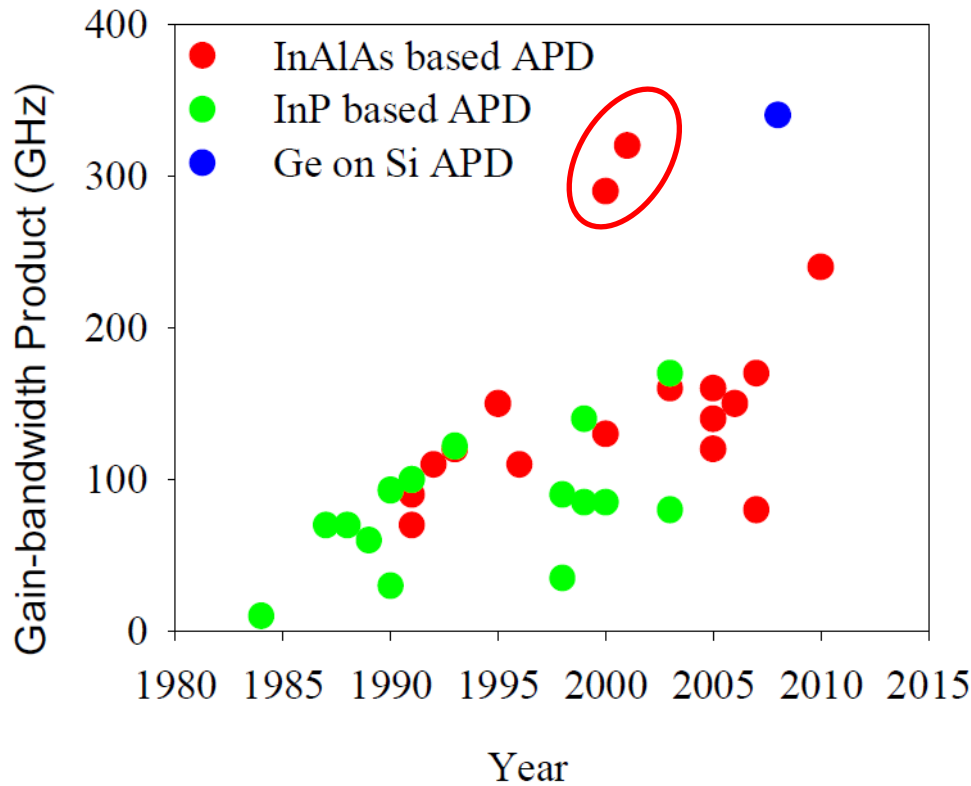
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# Motivation

# $\text{Al}_{0.48}\text{In}_{0.52}\text{As}$ as a promising APD multiplication layer

## Advantages over InP

S. Xie doctor of philosophy University of Sheffield (2012).

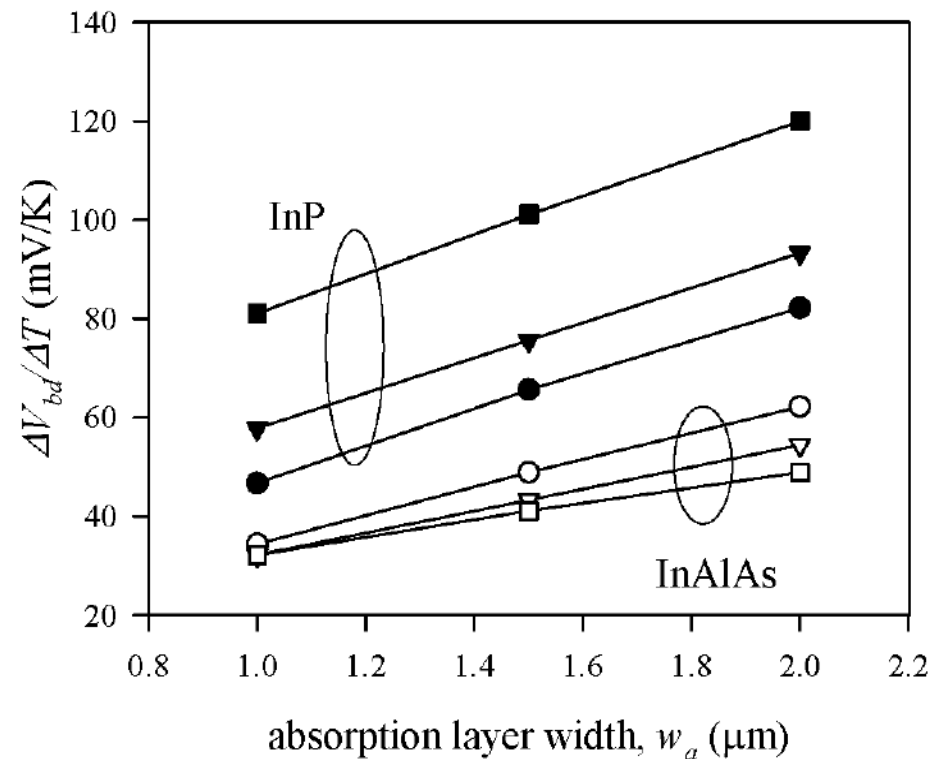
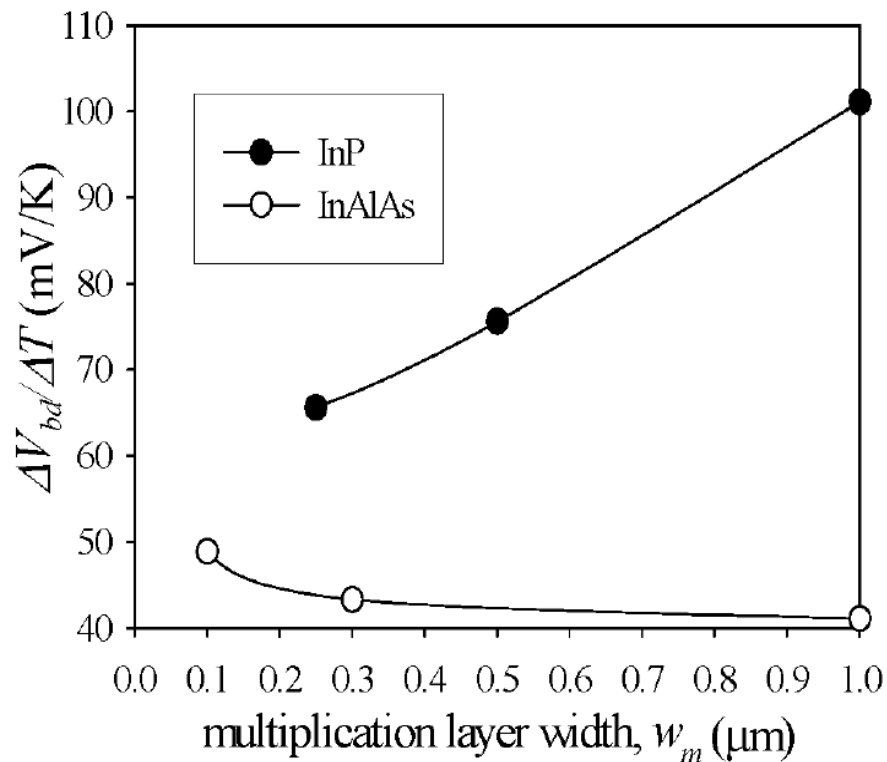


- ❖ High performances
- ❖ High sensitivity
- ❖ Adapted to high bit rate

# $\text{Al}_{0.48}\text{In}_{0.52}\text{As}$ as a promising APD multiplication layer

## Advantages over InP

D.S.G.Ong et al. 19th IPRM (2007)



- ❖ Better thermal stability for  $V_{br}$
- ❖ Device temperature control not critical

# $\text{Al}_{0.48}\text{In}_{0.52}\text{As}$ as a promising APD multiplication layer

## Challenges on APD

- ❖ Low noise
- ❖ High sensitivity
- ❖ High gain
- ❖ High GBP

## Advantages of $\text{Al}_{0.48}\text{In}_{0.52}\text{As}$

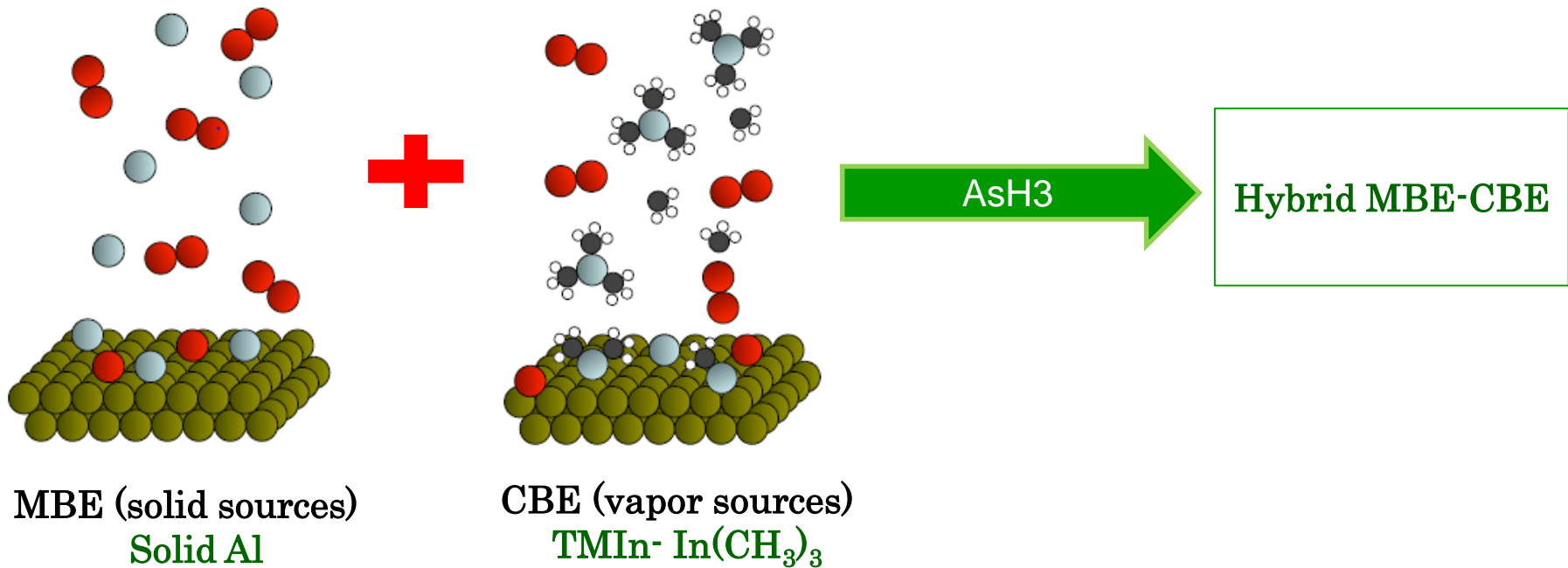
- ❖ Large band gap
- ❖ Low excess noise
- ❖ High ionization ratio
- ❖ Good Thermal stability

## Challenges on AlInAs growth

- ❖ Residual background doping (GS)
- ❖ Clustering effect (SS)
- ❖ Lattice matching control
- ❖ Control of cations migration (SS)

Need of a versatile and adapted growth approach

# Our approach: Hybrid MBE-CBE



## Advantages

- ❖ Low risk of contamination of Al based compounds
- ❖ Improve uniformity
- ❖ Reactor under UHV

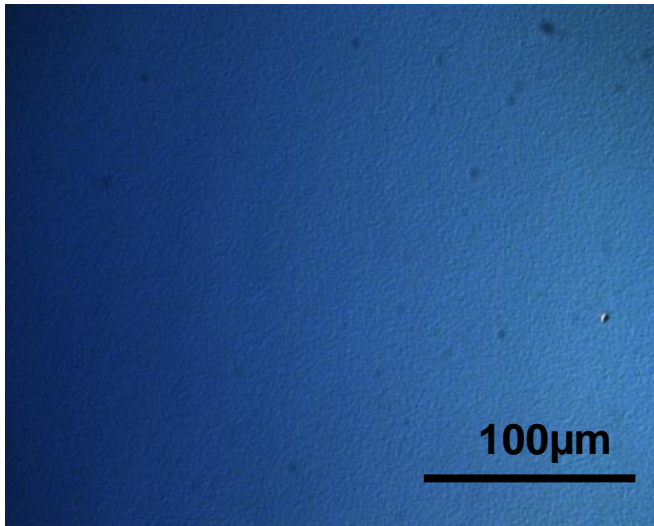
# Experimental results

# AllnAs growth by standard CBE using TEAI

## Growth condition

- ❖ TMIn, TEAI and cracked AsH<sub>3</sub>.
- ❖ Growth T = 500°C
- ❖ Growth rate = 0.61 μm/h

## Nomarski



## Epitaxial structure

Cap InP
AllnAs – Lattice matched
Buffer InP
InP:Fe substrate (001)

- ❖ **Poor surface quality**
- ❖ **Poor crystalline quality**
- ❖ **High residual background**

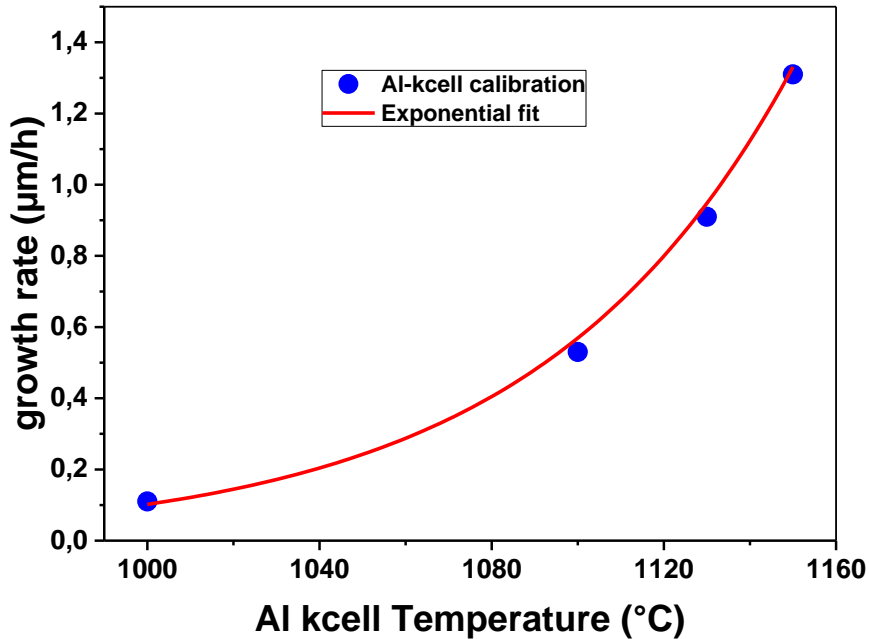


# Growth of hybrid AlInAs

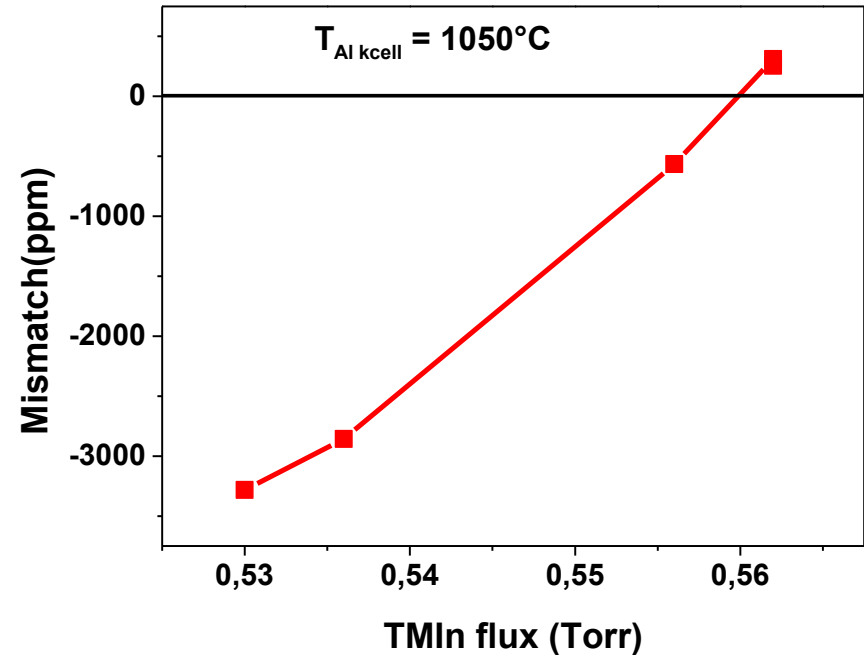
Using  $\text{In}(\text{CH}_3)_3$ , Solid Al and thermally cracked  $\text{AsH}_3$

# AllnAs growth: Sources calibration

## Al source calibration



## TMIn Flux Calibration



- ❖  $T\text{-kcell} = 1050^{\circ}C$ ,
- ❖  $TMIn = 0.56\ Torr$

# Intrinsic AlInAs growth by hybrid MBE-CBE

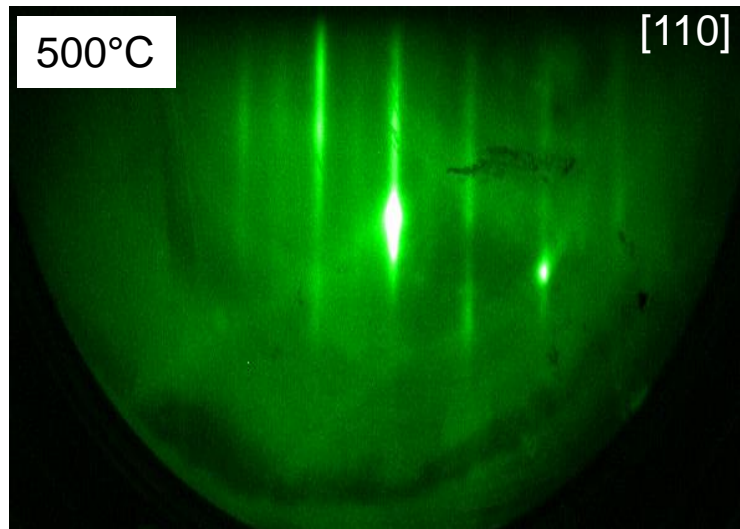
## Growth conditions

Sample ID	T <sub>MIn</sub> (torr)	Cracked AsH <sub>3</sub> (torr - °C)		T Al K-cell (°C)	Growth T (°C)	Growth rate (μm/h)
A	0,562	10	950	1050	500	0,34
B	0,556					
C	0,562					
D	0,562					

## Epitaxial structure

Cap InGaAs_5 nm
AlInAs
InP:Fe substrate (001)

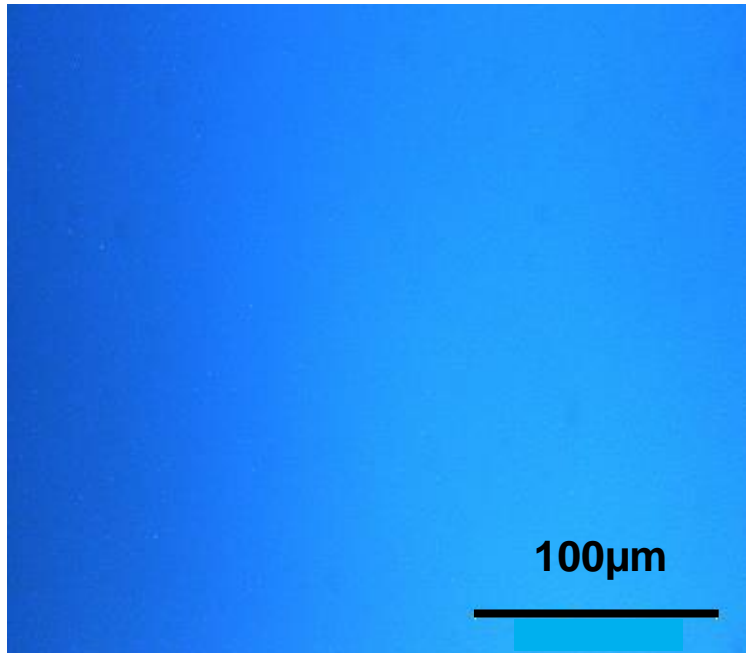
## RHEED pattern



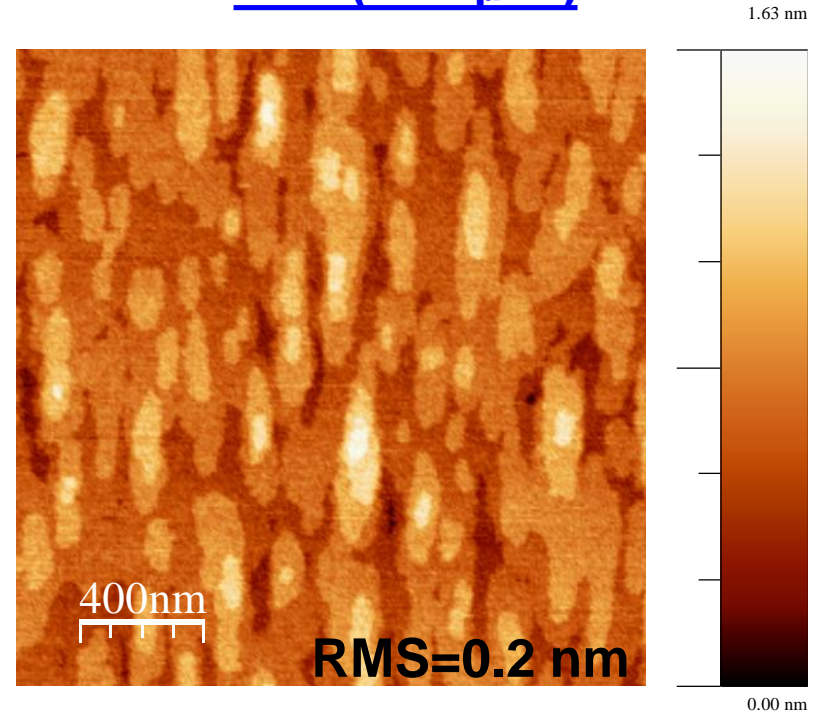
- ❖ Layer by layer growth mode
- ❖ Single crystal growth
- ❖ Good crystalline quality

# Hybrid AlInAs growth: morphology

Nomarski



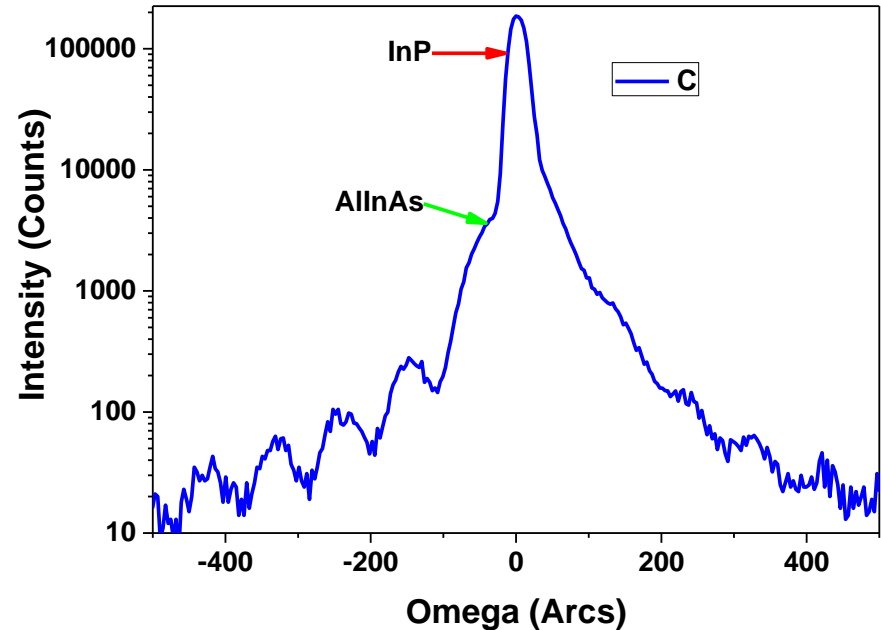
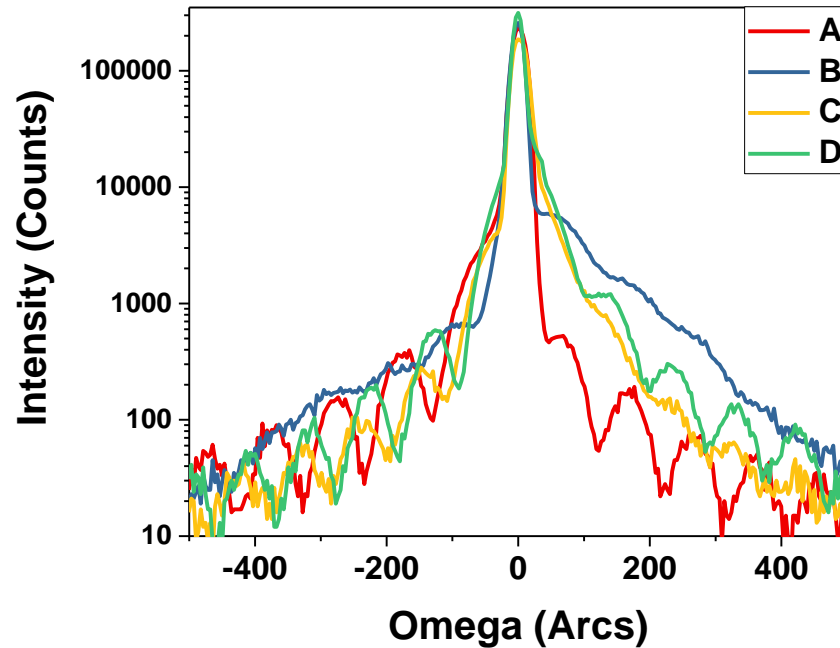
AFM ( 2x2 μm<sup>2</sup> )



- ❖ Homogenous surface
- ❖ No visible defects
- ❖ Smooth surface

# AllnAs growth: crystalline and structural quality

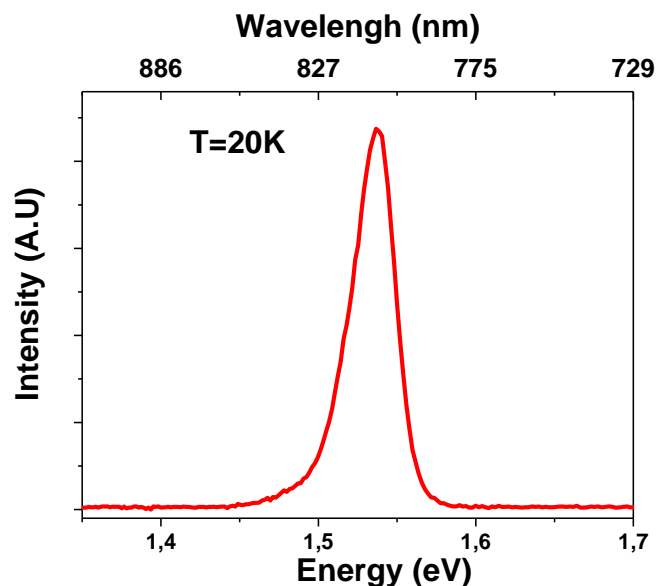
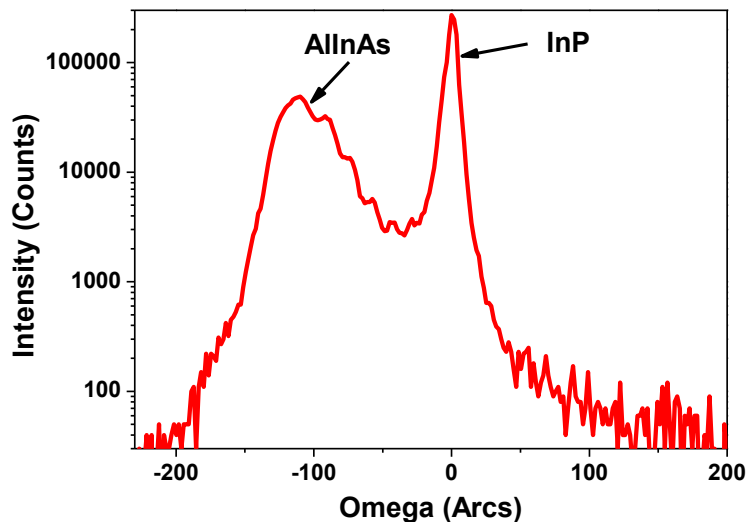
## HRXRD



Sample	mismatch	Composition %	Thickness ( $\mu\text{m}$ )
C	127 ppm	48 Al 52 In	0.3

- ❖ High structural quality
- ❖ High crystalline quality
- ❖ Sharp interfaces

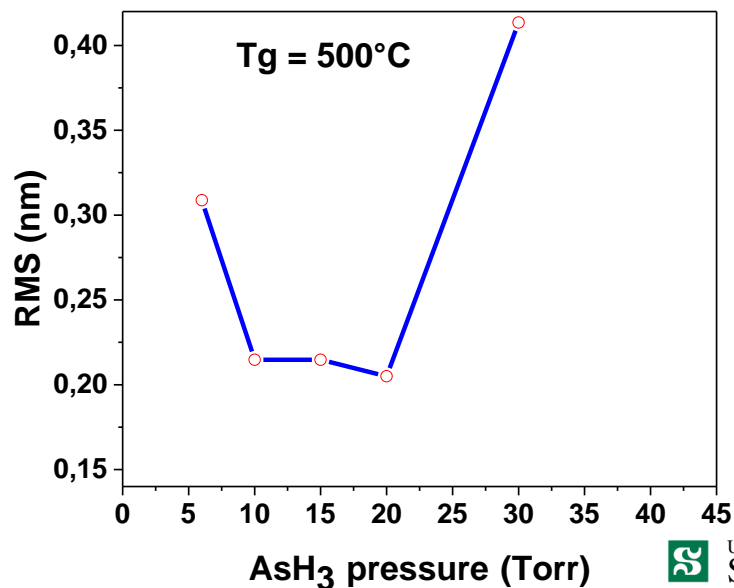
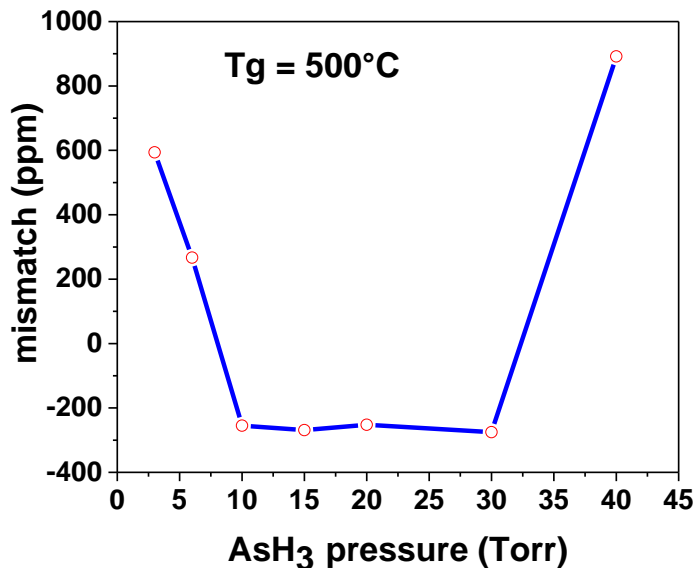
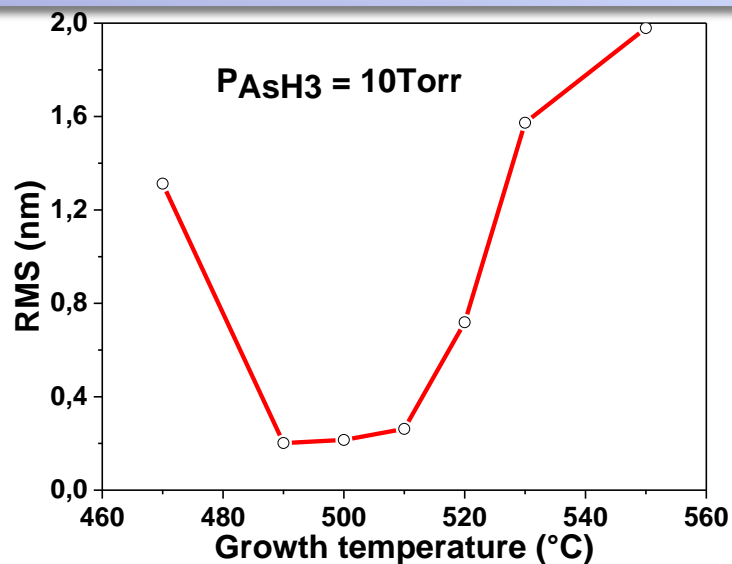
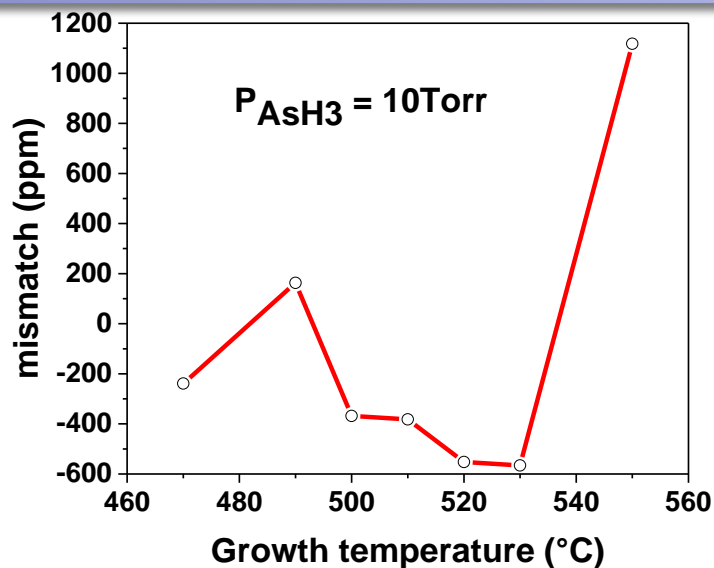
# Thick AlInAs growth: HRXRD, HE and PL



Sources	Carrier density (cm <sup>-3</sup> )
Organometallics (CBE)	<b>3E18</b>
Solid Al (Hybrid)	<b>3E15</b>

In plane mismatch	Composition % (XRD)	Thickness μm	FWHM epi-layer (Arcs)
<b>432 ppm</b>	47.3 Al 52.7 In	1.6	<b>42</b>
Eg	Composition % PL	Thickness μm	FWHM (meV)
<b>1.536 eV</b>	49 Al 51 In	1.6	<b>31</b>

# AllnAs growth: growth parameters effects



# Conclusion

- ❖ Hybrid OM-solid source epi growth has been demonstrated.
- ❖ Growth of good quality Al based compounds and others III-V materials.
- ❖ Promising approach for the growth of III-V materials based devices.

Mismatch (ppm)	RMS (nm)	E <sub>g</sub> (eV)	FWHM PL at 20K (meV)	Carrier density (cm <sup>-3</sup> )
140	0,2	1,51	8	7E14

- ❖ Next steps:
  - ❖ Optimisation of optical and electrical properties of AlInAs
  - ❖ Growth and fabrication of an AlInAs based APD



# Thanks for your attention!

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